Comprehensive Mission Design Architecture Trade Study for Planetary Defense Missions

Planetary Defense
Goddard Space Flight Center

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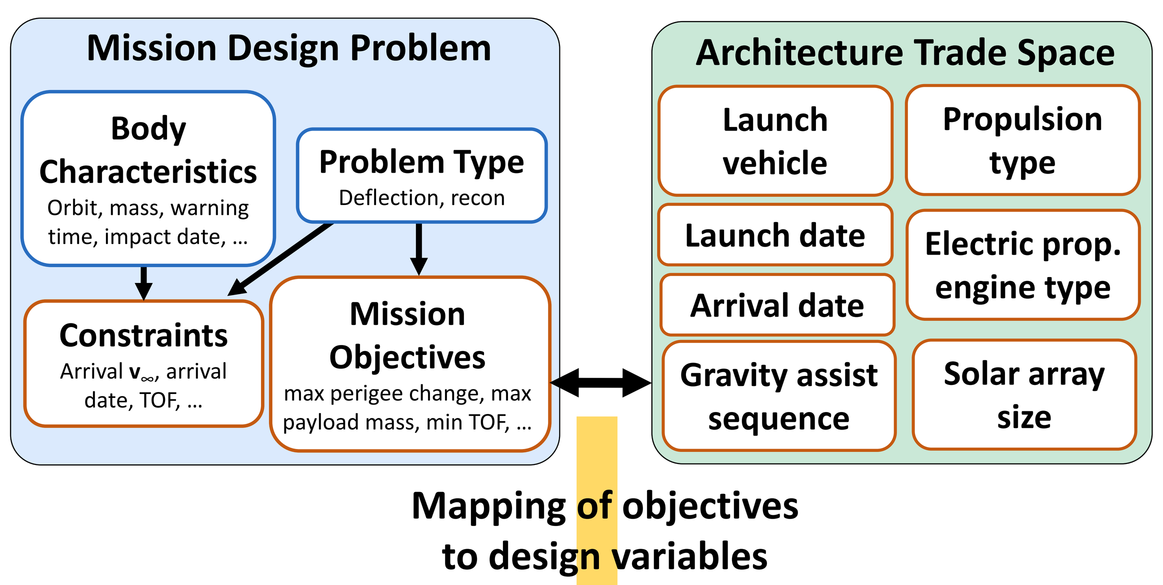
Introduction

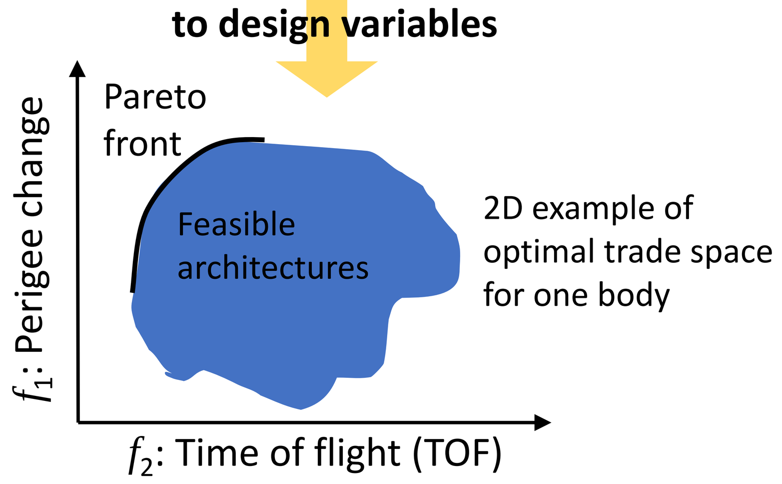
- Mission architectures are traditionally designed on a mission-by-mission basis due to problem complexity
- However, a comprehensive understanding of mission architectures best-suited for PD problems would:
  1. Allow for advance development of ready-to-build HW designs for most PD problems
  2. Catalyze development of new enabling technologies (e.g., NEP, NTP)
  3. Inform cost decisions for different mission types
  4. Reduce (or eliminate) Phase A design work

Objective

Map the PD architecture trade space to identify missions/spacecraft that are applicable to many PD scenarios & inform how to best invest in future technology

Background





Grid search is intractable:

$$2.7 \times 10^{13}$$

optimization problems given simulated pool of 27,000 impacting bodies & all trade space combinations

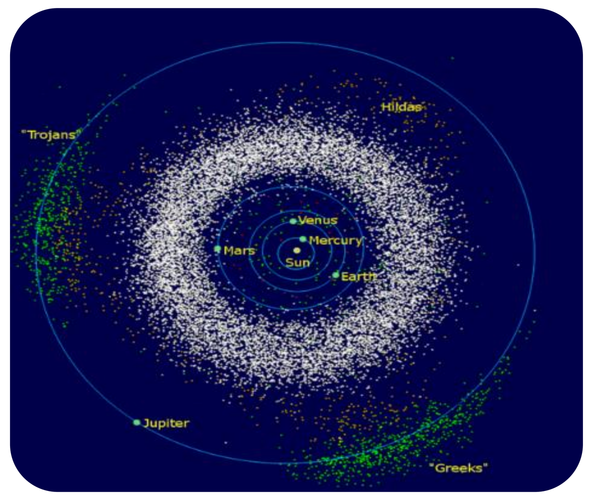
If each problem took only 2 minutes to optimize, it would take the age of the universe to complete the trade

Methodology

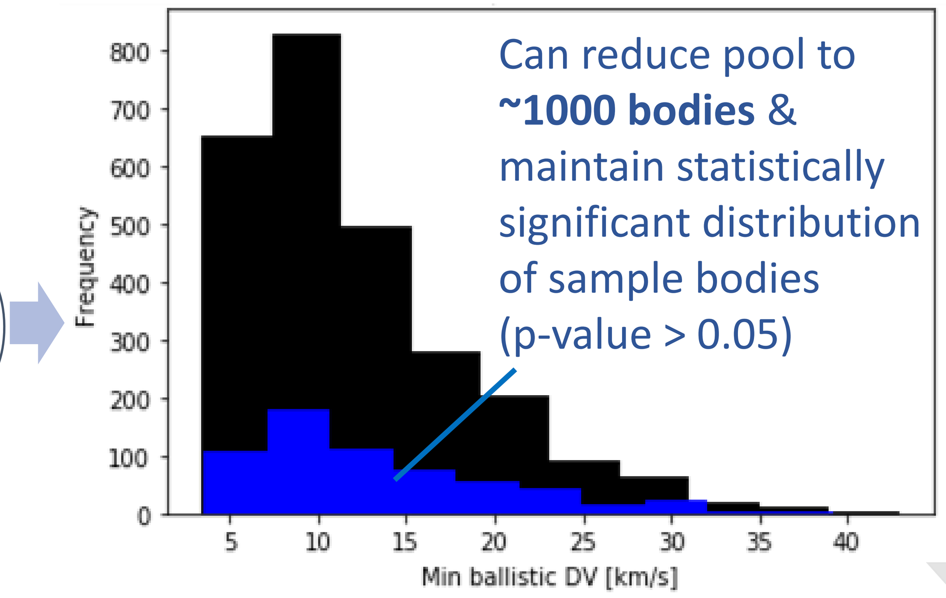
1. Body Down Selection

Select representative subset of bodies from full library population of 27,000 simulated impactors

Full set of simulated impactors
[Chesley et al., 2019]



k-means clustering based on *a, e, i, p*, TOF, energy & Hohmann ΔV



2. Mission Design Problem Categorization

Define mission design categories & formulate tractable mission design optimization problems

PD Objective	Propulsion Type	Optimization Objectives
1 Reconnaissance	chemical	Delivered mass, TOF, arrival date, arrival V-inf, launch vehicle (LV) class
2 Reconnaissance	SEP	Delivered mass, TOF, arrival date, arrival V-inf, LV class, solar array size, # of thrusters
3 Intercept NED deflection	chemical	Delivered mass, TOF, arrival date, arrival V-inf, LV class
4 Intercept NED deflection	SEP	Delivered mass, TOF, arrival V-inf, LV class, solar array size, # of thrusters
5 Rendezvous NED deflection	chemical	Deflection perigee change, delivered mass, TOF, LV class
6 Rendezvous NED deflection	SEP	Deflection perigee change, delivered mass, TOF, LV class, solar array size, # of thrusters
7 Kinetic impactor	chemical	Deflection perigee change, delivered mass, TOF, LV class
8 Kinetic impactor	SEP	Deflection perigee change, delivered mass, TOF, LV class, solar array size, # of thrusters

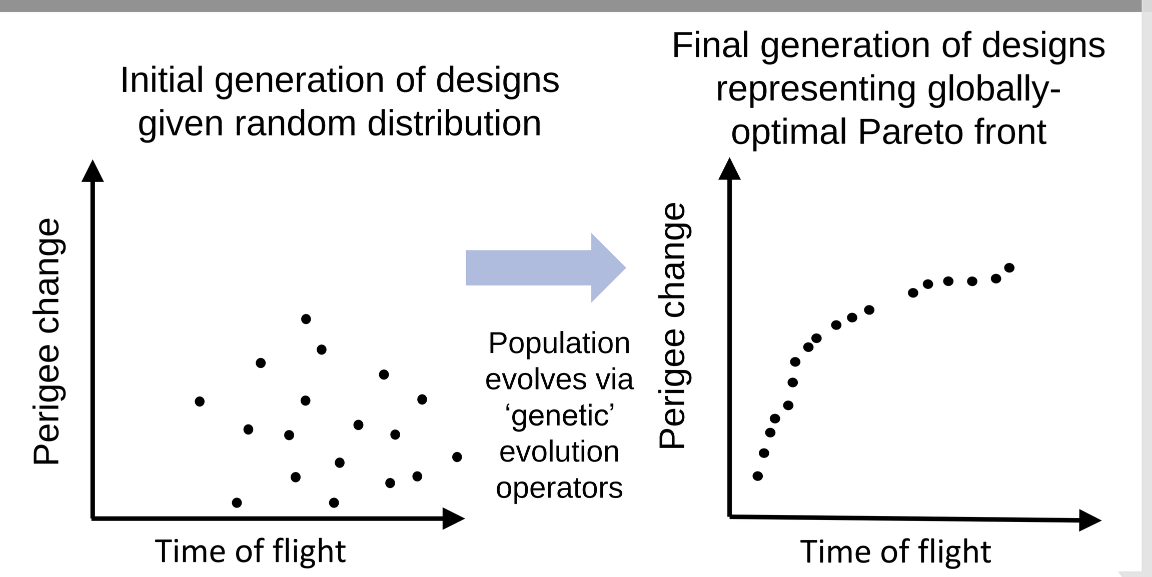
Each case is a coupled systems & trajectory optimization problem with many objectives

3. Mission Optimization

Efficiently trade mission architectures for each down-selected body & each mission design category with stochastic, many-objective optimizer

Systems-trajectory problem solved simultaneously → genetic algorithm applied as outer-loop **stochastic systems optimizer around gradient-based inner-loop trajectory optimizer**

- NSGA-III algorithm solves many-objective systems optimization problem
- ‘Monotonic basin hopping’ + ‘sequential quadratic programming’ optimizes trajectory

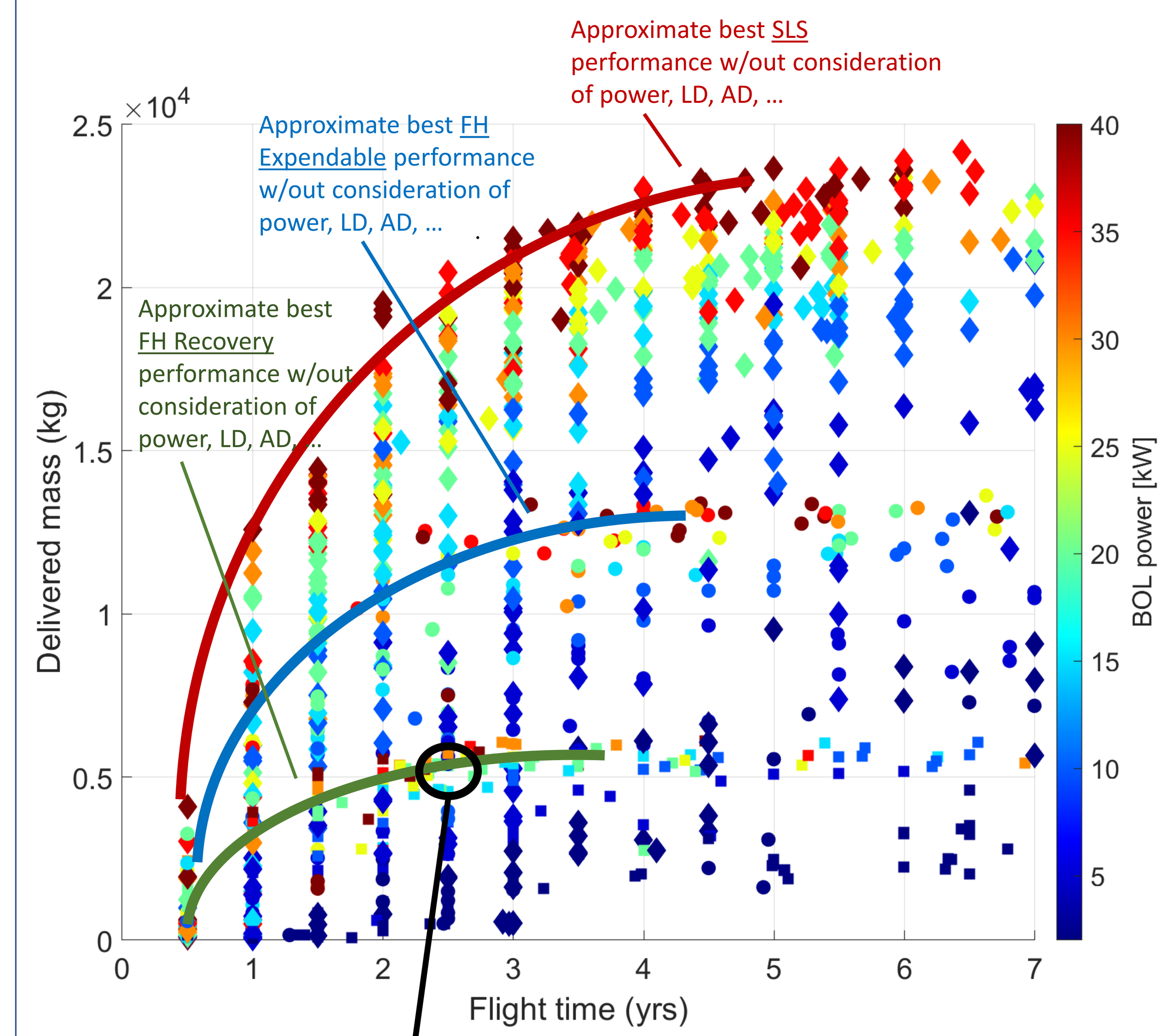


4. Catalog Solution Space

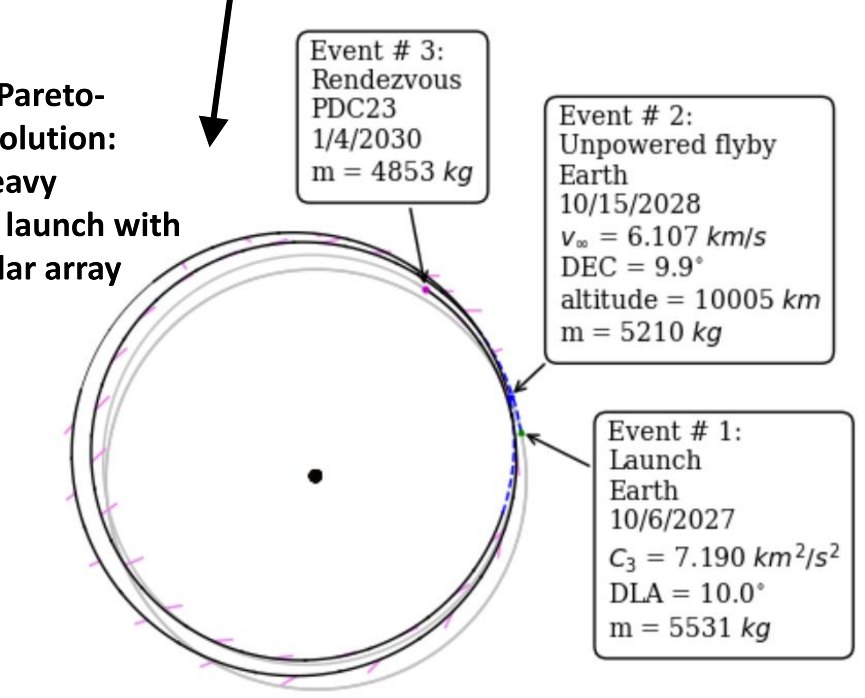
Classify & synthesize design space to solution space mapping for easy look up of optimal trade space given a specified PD problem

Example Results

Projection of LV-mass-TOF-power Pareto front representation for a SEP rendezvous deflection mission



Example Pareto-optimal solution: Falcon Heavy Recovery launch with 15 kW solar array



- Pareto front representation generated for each down-selected body in each problem category to generate full data set
- Strategic & automated sampling of design space via stochastic optimization enables efficient & broad mapping

Next Steps

- Finalize outer-loop wrapper development for many-objective optimization
- Run full trade on NASA Advanced Supercomputing processors
- Develop cataloging approach of solution space mapping
- Analyze results to identify top-performing architectures